UNITED STATES AIR FORCE MATERIALS TECHNOLOGY HIGHLIGHTS

Air Force Research Laboratory

Materials & Manufacturing Directorate

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Scientists Develop Ceramic-Based Body Armor for Use by Warfighters

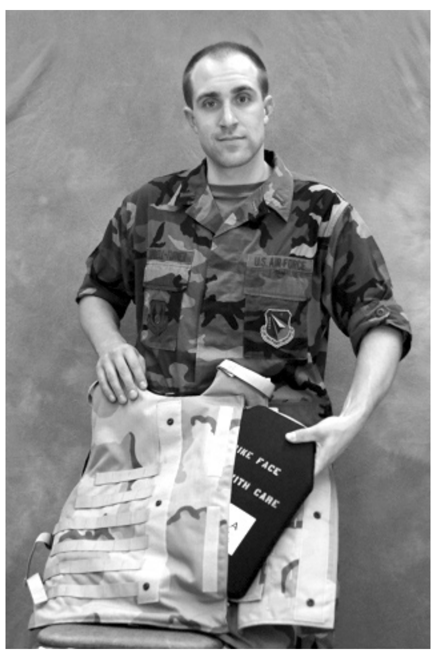
Scientists and engineers from the Air Force Research Laboratory Materials and Manufacturing Directorate (ML) have helped develop a novel metal-ceramic hybrid material that is being used in higher-performance, lighter-weight and lower cost Small Arms Protective Inserts (SAPIs) for body armor vests.

Teaming with Excera Materials Group of Columbus, Ohio, and using EMTEC Cooperative Technology Exchange Program, Navy Phase II Small Business Innovative Research and ML laboratory director's funding, the group developed a prototype SAPI strike plate that is already exceeding the Army's performance standards for fielded applications.

In May 2003, ML's director challenged the unit's company grade officers to develop workable basic and applied research and development projects that would provide rapid-response technology solutions to current, real-world threats. An ML lieutenant proposed an idea based on using geometric means to stop a bullet. He proposed that ML create a lightweight, layered composite panel with external angled tiles that would cause bullets to "tumble and stop" instead of piercing armor plating on tanks and aircraft. However, when ML scientists discovered that there were only three SAPI strike plate manufacturers in the U.S. managing the current war time demand for body armor, ML's program evolved into developing a lighter-weight, metal-infused ceramic laminate for personal "flak" vests worn by airmen and soldiers on the battlefield.

In order to stop an assault rifle bullet, armor must have properties that will squish, crack or blunt the point of a bullet. The material must also have a fiber backing that will catch bullet fragments and absorb the pressure wave generated when a bullet makes contact with armor. Developing ceramic materials that will retain the high hardness, even in the shapes required for body armor applications is a daunting task. All of the current SAPI plates are composed of press sintered ceramic materials, which are very hard, but also make the strike plates heavier and more fragile than they could be.

ML scientists contacted Excera, who were making a unique ceramic material called ONNEX, which they hoped to apply to brake rotors and rocket motor impellers for high heat environments. Excera's ONNEX material is developed by infusing a ceramic material with liquid aluminum. This material offers the high hardness of boron carbide, but also provides the benefit of high fracture toughness that is estimated at ten times that of other pressed ceramic materials. This means that when a bullet hits the armor, the hardness characteristics will break the bullet open and stop it, and the fracture toughness permits multiple shots to the same region because damage is confined to a very small area. The ML/Excera team backed the material with a ballistic fiber backing made from Dyneema and Rhino lining (which is also used in truck bed liners) and began extensive testing on their application. The complete ML/Excera SAPI system is lighter than currently deployed systems.



2nd Lt. T.J. Turner, Air Force Research Laboratory Materials and Manufacturing Directorate, demonstrates how a Small Arms Protective Insert fits into a personal "flak" vest. The lieutenant spearheaded a cost-effective, rapid effort to develop the body armor to help protect U.S. warfighters from assault and other weapons fire. (U.S. Air Force photo)

In August 2004, the application underwent extensive ballistic tests at H.P. White Army Proving Ground in Maryland. When the technology exceeded the ballistic specification required for current SAPI strike plates, the Army developed a contract with Excera for low-rate production of the new body armor front and back strike plates. The Army will deploy the new armor to troops as it is produced.

In the meantime, scientists at ML are conducting follow on testing to optimize the material and to develop a unique laminate with Excera's ONNEX material. ML is also working closely with Air Force Special Forces units to develop future form, fit and function testing, which will provide feedback on how the technology performs during operational exercises.

Other applications for the new material are also being reviewed. ML scientists have suggested that the material may be appropriate for the Defensive Fighting Position, a structural protection used against enemy attacks, a Deployable

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Brake-By-Wire Technology Could Lead to Improved Unmanned Aerial Vehicles

The Air Force Research Laboratory Materials and Manufacturing Directorate and the National Center for Industrial Competitiveness (NCIC) concluded an innovative, two-year Cooperative Research And Development Agreement enabling design, construction and successful demonstration of a commercially viable brake-by-wire (BBW) system for next generation automobiles, using technology developed for military aircraft.

The technical knowledge and insight gained from this experiment enables Delphi Automotive Systems to compete globally in the development of both hybrid and full-electric BBW design options, and allows the Air Force, via a follow-on agreement between Delphi and the Laboratory's Propulsion Directorate (AFRL/PR), to pursue design and development of a reduced cost, high performance electro-mechanical braking system for unmanned aerial vehicles (UAVs).

Conventional automobile braking systems use hydraulics, but that could change someday as a direct result of the two-year research and development project initiated by the Materials and Manufacturing Directorate (ML) and NCIC.

The project called for no less than successful design, development and demonstration of a full-electric BBW system on a sports utility vehicle, the GMC Envoy. To achieve this, the principal agent for the experiment, Delphi Automotive Systems of Dayton, Ohio relied heavily on fly-by-wire technology and landing gear expertise developed and honed by the Air Force.

Delphi received support, including funding, project management and engineering perspective from ML, as well as the AFRL Air Vehicles and Propulsion Directorates, Edison Materials Technology Center (EMTC), Wright Technology Network (WTN), the State of Ohio and a number of suppliers, mostly from the Dayton area, and the University of Dayton. ML assisted with wiring and interconnection devices, PR contributed its expertise in high temperature electrical actuator components, and the Air Vehicles Directorate (AFRL/VA) provided technical know-how in control applications.

Advancements in semiconductors and computers in recent decades have led to greater cooperation and technology sharing between the automotive industry and Air Force science and engineering. Several of these advancements have been driven by federal government regulations instituted during the late 1970s, mandating improvements in automobile emissions control and fuel economy. Comfort and safety have also been motivating factors. Examples include electronic fuel injection, cruise control, computerized engine diagnostics, air bags, climate control systems, and power mirrors.

George A. Slenski and George F. Schmitt

Eliminating hydraulics has been a goal for the Air Force for a number of years. The change to electro-mechanical braking systems would be more environmentally friendly and would offer great opportunities for enhanced vehicle safety, mission survivability, and manufacturing efficiency. The fundamental need has been to advance the technology to a stage where electro-mechanical activation is competitive with the very mature hydraulic systems. The knowledge obtained from this BBW research and development effort has increased that potential. Two design iterations for electric calipers and two systems (full brake-by-wire and hybrid brakes) were developed under the program, culminating in the demonstration of a fully integrated electric caliper and a full BBW-equipped GMC Envoy. Significant technical challenges remain before BBW will be available on commercial vehicles. Nevertheless, a significant step towards full-scale production has been achieved.

The BBW project demonstrates that government and private industry can work together to advance mutually beneficial technology objectives. About 50 potential invention ideas have been recorded and 22 U.S. patent applications have been or will be filed as a result of this effort, and Delphi now has the capability to pursue BBW applications globally. PR will gain important technical insights through the follow-on research and development agreement with Delphi, and ML's Systems Support Division has gained critical new understanding in wiring and interconnection devices applicable to active inventory and future aerospace flight systems. The BBW project has the potential for reducing component costs through shared demand and leveraging investments in more electric aircraft, and provides needed large-scale technology validation.

George F. Schmitt, chief of the ML Integration and Operations Division, who was instrumental in the program's administration and eventual success, received the Federal Laboratory Consortium of Technology Transfer Midwest Region's annual Technology Transfer Award for orchestrating the AFRL effort. George A. Slenski served as principal technologist for ML's Systems Support Division.

Successful design, development and application of BBW technology benefits the consumer, the automotive industry and the Air Force. BBW technology offers demonstrated potential for improving how brake systems are manufactured and implemented, and is technologically promising in terms of enhanced safety and vehicle stability at costs comparable to or less than conventional hydraulic braking systems. Planned follow-on research efforts between Delphi and AFRL/PR could lead to lighter weight braking systems for UAVs, extending their reach and reducing fuel consumption costs.

For more information, contact the Materials and Manufacturing Directorate's Technical Information and Support Center at techinfo@afrl.af.mil or (937) 255-6469. Refer to item 04-219.

MEMS Switch Simulator Uncovers Material Properties

Scientists at the Air Force Research Laboratory's Materials and Manufacturing Directorate (ML) have developed a highly sophisticated laboratory instrument that simulates the effects of physical forces and electrical current on microelectromechanical systems (MEMS) switches.

The simulator's performance, honed through meticulous attention to detail over many years of study and investigation, has led to revolutionary insights into how micro-scale switches work and what causes them to fail.

MEMS switches offer substantial performance enhancement over current electromechanical (EM) and solid state (SS) switches, and have demonstrated great potential for military and commercial applications, with radio frequency (RF) applications particularly promising.

MEMS switches, so small they require high-powered microscopes to be seen, offer a significant performance edge over EM and SS switches. Realizing this potential, however, requires a greater understanding of the contact physics of electrode materials, which can only be attained through improved knowledge and a better characterization of material properties down to the nanoscale. Among the switch devices presently used in RF systems, EM relays offer the best high frequency performance in terms of low insertion loss, high isolation and good power handling (up to several watts).

Unfortunately, EM devices are large, slow, expensive, and lack durability. Solid state switches, on the other hand, offer chip-level integration, small size, fast switching times, excellent durability and low cost. However, as a rule, they do not perform well in broadband applications, have high insertion loss, and poor isolation. As a result, when choosing between EM and SS switching, there is generally a trade off between the high frequency performance offered by EM and the durability, size, low cost and switching speed of SS. In addition, high losses in SS switches tend to nullify the size benefits, due to the need for signal amplifiers, which increase power consumption and complexity. The attraction of MEMS RF switches is that they offer the performance of EM switches with the durability, size and low cost of SS devices.

Prior to ML's involvement in MEMS switch research and the development of a switch simulator (one of only a few such instruments in the world), there was little understanding of the factors determining the performance and reliability of these small devices. Scientists in the Directorate's Nonmetallic Materials Division Nonstructural Materials Branch used their in-house built simulator in a unique way: to study contact resistance (R) and micro-scale surface forces in gold (Au) contacts used in direct current (DC) MEMS switches; then they connected fundamental properties to performance, with an emphasis on the effects of contact force and electric current on R, micro-adhesion, and reliability and durability.

Experiments were performed in a well-defined air environment under precisely controlled operating conditions. They revealed that microadhesion was the failure mechanism at low current (0-100 microamps (µA)), and that switch shorting was the cause of failure at high current (1-10 milliamps (mA)). Electric current, the experiments showed, had a profound effect on deformation mechanisms, adhesion, R, and reliability and durability. Asperity creep, switch bouncing, and switching induced adhesion were present at low current, while near zero adhesion, asperity melting and switch shorting by nanowire formation were present at higher currents. The presence of a film containing carbon and oxygen along with switch contact load versus resistivity data suggested that tunneling was a significant charge transfer mechanism at both low and high current. The experiments also revealed that adhesion was linked to the creation of a smooth surface texture through repeated switch actuation (i.e., asperities were hammered atomically flat), and that surface roughening by nanowire formation prevented adhesion at high current levels.

Key outcomes include: microadhesion is the dominant failure mechanism at low current and becomes apparent as contact surfaces are flattened during actuation; short circuits are the dominant failure mechanism at high current and are formed by nanowires drawn from melted asperities; and quantitative relationships among switch actuation force, ambient environment, current density, and performance have been established for use by MEMS designers. In the past, switch designers knew switches failed; now, they have significant insight as to why. Armed with this data, designers can build durable, more robust switches. The research is also applicable to simple pressure contacts used in connectors, sockets, and chip holders—a growing concern as the number of inputs and outputs increase and apparent contact sizes decrease.

MEMS RF switches provide a number of significant advantages over current EM and SS switches. These include: (1) high linearity; (2) low insertion loss; (3) low power consumption; (4) reduced size; (5) high shock resistance; (6) wider temperature range; (7) good isolation; and (8) low cost. Enhanced performance and reliability will lead to improvement in currently existing systems and create a new paradigm for future system development. Functional MEMS RF switches will benefit the Air Force and the private sector in important areas such as radar, aviation instrumentation and cellular phones.

For more information, contact the Materials and Manufacturing Directorate's Technical Information and Support Center at techinfo@afrl.af.mil or (937) 255-6469. Refer to item 04-117.

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Defensive Panel System that ML engineers at Tyndall AFB, Fla., are developing, and for appendage armor, an insert that slips into pockets on the arms or legs of a soldier.

In just 18 months, this low-cost, high payoff technology development program has evolved from initial laboratory research and development work into a technology system that exceeds the capabilities of most current SAPI plates. If the technology continues to perform beyond specification requirements, ML scientists expect that several military branches will purchase the technology at a cost savings of roughly $400 per armor vest, and a total cost savings to the Department of Defense that is in the millions.

For more information, contact the Materials and Manufacturing Directorate's Technical Information and Support Center at techinfo@afrl.af.mil or (937) 255-6469. Refer to item 04-390.

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